NOAA Data Report ERL PMEL-23

EPOCS MOORED TEMPERATURE, CURRENT AND WIND MEASUREMENTS: 0°, 140°W; MAY-JUNE, 1987

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Michael J. McPhaden

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Director

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1. INTRODUCTION

This report contains temperature, current and wind data measured during May and June, 1987, in the eastern equatorial Pacific. Ocean current and temperature data were obtained from Equatorial Pacific Ocean Climate Studies (EPOCS) mooring EC65 located at 0° 0.2'N, 139° 55.4'W. This taut-line surface mooring was instrumented in the upper 300 m with an array of seven EG&G Vector Averaging Current Meters (VACMs), 14 Sea Data Microloggers (TRs), two Sea-Bird Conductivity and Temperature Recorders (SEACATs) and a Vector Averaging Wind Recorder (VAWR) (Figure 1). VAWR wind and air temperature data proved unusable, so measurements from a mooring 21 km to the west (mooring EW62, 0° 0.9'S, 140° 6.7'W) are also included in this report. EW62 was instrumented with an Argos Meteorological Package (AMP), which internally records and telemeters data in real time via the Argos system.

EC65 was deployed on May 12, 1987, and recovered on October 13, 1987, spanning a five month period during which El Niño conditions existed over much of the tropical Pacific. Ten instruments were programmed to sample temperature at 1-minute intervals in the upper 101 m during the first two to four weeks of deployment. These data were collected as part of a collaborative study involving EPOCS and TROPIC HEAT (Eriksen, 1985) to examine the relationship of high frequency internal wave processes to vertical mixing and to large scale current and temperature variability. Data from the total 5-month record will be included in a forthcoming report covering several mooring deployments at the EPOCS 110°W and 140°W sites.

2. INSTRUMENTATION

2.1 Temperature Measurements

The VACM samples temperature nearly continuously (500-1000 Hz) from a thermistor mounted inside the pressure case. The VAWR measures air temperature and sea surface tempreature (SST) in a similar manner. Air temperature is measured from the buoy tower at 3 m above the surface. The SST thermistor is attached to the buoy bridle about 1 m below the surface. VACM and VAWR data are recorded as 15-minute averages. The AMP samples air temperature at 3 m above the surface at a 2-Hz rate and outputs 2-hour averages. The TR measures instantaneous values, with six units set to sample at 15-minute intervals and eight at 1-minute intervals. Six of the fast sampling units had data tape capacities of about 14 days. The other two had solid state memories with storage capacities of 19.0 and 30.5 days. Since the TRs were turned on about 12 hours prior to deployment the actual data return for the fast sample rate instruments was expected to be slightly less than the above maximum capacities.

The SEACATs measure instantaneous values and were programmed to sample at 1-minute intervals for 14 days at the beginning and near the end of the deployment, and at 15-minute intervals in between. These instruments were new and both failed due to improper handling and assembly prior to delivery from the manufacturer. No data was recovered from either instrument for inclusion in this report.

The VACM/VAWR's and TR's have different temperature response time constants. The VACM time constant is relatively slow (~100 s, Payne *et al.*, 1976; Levine, 1981) since the sensor is inside the pressure case. The sensor on the TR is outside the case and has a much faster response. Laboratory tests at PMEL indicate a response time (time to reach 65% of equilibrium value in response to an imposed temperature step) of 10 s. Least significant bit resolution is an increasing function of temperature for the TR and has a value of 0.016°C at 30°C. For the VACM it also varies with temperature, but is less than 0.001°C at all temperatures.

All temperature sensors were calibrated prior to deployment. The VACM/VAWR calibration was performed in two parts. The voltage to frequency converter (V/F) was calibrated by applying precision resistors and measuring the response. The VACM/VAWR thermistors were calibrated at NOAA's Northwest Regional Calibration Center (NRCC). Combined residual error of the two calibrations is no larger than the NRCC temperature bath accuracy of 0.005°C. The TR's were calibrated at NRCC as a complete unit. Maximum residuals were 0.045°C or less.

All instruments were similarly calibrated after recovery. The VACM post-deployment calibration equations differed from the pre-deployment calibrations by no more than .01°C with the exception of the 25-m instrument which had drifted by .07°C. A time dependent linear combination of the pre- and post-deployment calibrations was used on this time series. The TR's all recalibrated to within .06°C of the pre-deployment calibration. Thus, we would characterize the instrumental accuracies of the VACM and TR temperatures as 0.01°C and 0.06°C, respectively.

2.2 Current Velocity Measurements

The VACM measures current velocity using a Savonious rotor and vane (Freitag *et al.* 1987). Tow tank runs performed by PMEL indicate that the rotor is accurate to within 1.2 cm/s in steady flow. However, laboratory tests in nonsteady flow as summarized by Beardsley (1987) indicate that mean speeds may be biased high due to a combination of imperfect cosine response of the rotor, overspeeding and noninstantaneous response of the vane to changing flow direction. The size of this bias has been measured in field tests from surface moorings in hydrodynamic conditions typical of the eastern equatorial Pacific, i.e. light winds, small surface waves and strong currents (Halpern, 1987). Comparisons were made between VACM's and Vector Measuring Current Meters (VMCM's; Weller and Davis, 1980) which are generally considered more accurate in unsteady flow. VACM mean speed at 13 m was 12% higher than for a VMCM at 14 m. This bias decreased to 5-7% in the undercurrent based on measurements from VACM/VMCM pairs near 100 m and 160 m. Note however, that the VMCM tends to underestimate mean speed in nonsteady flow by a few percent (Beardsley, 1987), so not all of the above bias can be attributed to the VACM.

2.3 Wind Velocity Measurements

The VAWR is an inverted VACM with rotor and vane replaced with Climet wind cups and a balanced wind vane (Freitag *et al.*, 1988). Unfortunately, wind data recorded by the VAWR were unusable and will not be considered further in this report. Two-hour vector-average AMP wind data from mooring EW62 have been substitued for the VAWR winds. The AMP uses a R.M. Young propeller-vane wind sensor and samples at 2 Hz. Pre-deployment calibrations of the AMP had a maximum residual of 0.17 m/s and a resolution of 0.19 m/s. For a similar VAWR/AMP pair separated by 11 km at 0°, 140°W between October, 1986 and February, 1987, mean differences in vector wind components were 0.15 m/s or less and correlation coefficients were 0.97 or larger (Freitag *et al.*, 1988).

3. DATA RETURN

A total return of 610 instrument-days of ocean temperature data was possible for the period May 12 to June 11, 1987. This assumes a 13.5-day capacity for the 1-minute TR's with tape recorders and 18.5- and 30.0-day capacity for the 1-minute TR's with solid-state memory. The actual data return was 532 instrument days or 87%. Data return by instrument is listed in Table 1.

The two SEACAT's returned no data and accounted for 77% of the ocean temperature data loss. Additional data was lost from the 1-minute TR's at 36 and 101 m. The tapes from these instruments were very noisy and resulted in no data return at 36 m and a 40% data loss at 101 m.

Other TR's on this mooring had noisy cassettes but data losses were less than 1% of the expected return for each instument. The actual tape capacity was fairly variable, ranging from 12.1 to 15.6 days. The problem with noisy tapes from the TR's has been ongoing and appears to have no simple solution.

The VACM's returned 100% of possible current data. Air temperature from the VAWR was intermittently bad over most of the record and has been considered a total loss. Thus, we have substituted 30.1 days of air temperature from the AMP on mooring EW62.

4. DATA PROCESSING

After recovery of the instruments, the data tapes were translated at PMEL and the data transfered to a VAX 11/785. The raw data were processed by computer programs which assign a time to each data record, apply the pre-deployment calibration coefficients and check for obviously bad data. Standard statistics, histograms, time series and spectral plots were generated and checked for other errors such as spikes.

As an additional consistency check, hourly temperature differences between nearby instruments were computed and examined for inversions. Inversions may be the result of instrusive activity across the equatorial salinity front in the central Pacific (McPhaden, 1986) or overturning associated with turbulent bursts which have time scales of several hours and vertical scales of O(10 m) (Moum *et al.*, 1988). However, they may also indicate systematic measurement errors.

Given that in general the error of VACM and TR temperatures is estimated to be no more than 0.01°C and 0.06°C respectively, the error in temperature differences should typically be no more than 0.12 for TR/TR pairs, 0.07°C for VACM/TR pairs and 0.02°C for VACM/VACM pairs. Two instrument pairs had significant periods with temperature inverions. For the 45-m VACM - 46-m TR pair inversions occurred during 76% of the 13.5-day record, but exceeded 0.07°C for only 2% of the record. The maximum inversion was 0.09°C. Most of these inversions may be due to instrumental error, though the largest may be real.

Inversions were also found for extended periods between the 25-m VACM and the 35-m TR. The mean temperature at 25 m was 0.05°C warmer than at 35 m, but inversions occurred during 49% of the five month deployment. About one quarter of these inversions (12% of the total record) had values in excess of 0.07°C. The maximum hourly inversion was 0.12°C. As noted above, the 25-m VACM thermistor drifted by 0.07°C between pre- and post-deployment calibrations. Temperatures were corrected assuming a linear drift although the actual time history of the drift is unknown. Assuming a more conservative estimate for the accuracy of the 25-m VACM of 0.05°C a significant percentage of inversions between the 25-m and 35-m pair may be due to instrumental error.

5. TEMPERATURE DATA PRESENTATION

Hourly average temperatures are plotted in Figure 2. The time series have been grouped by depth with different scales for air temperature, for near surface temperature (1 to 61 m) and for thermocline temperature (80 m to 300 m). The data loss at the 101-m level is amplified in this figure by the method of computing hourly averages. If any of the 1-minute values in a 60-minute interval were bad the average value was flagged as bad and a gap appears in the solid line. The dashed line at the 101-m level is the result of linear interpolation of the gaps in the 1-minute data followed by hourly averaging.

Temperature statistics of each time series are listed in Table 2 and mean temperatures and standard deviations are plotted in Figure 3. The 1-minute TR data which have record lengths less than 30.1 days have slightly different statistics than nearby longer time series due to a net warming in May and June. Nevertheless, the consistency of statistics among closely spaced instruments is an additional indication of the level of accuracy of the data. The minima in standard deviation at the 250-m instrument is due to its location near the middle of the thermostad. SST was more than 2°C warmer and the thermocline was about 30 m deeper than usual, reflecting the 1986-87 El Niño conditions.

Spectra of temperature time series are shown in Figure 4 for all but the 101-m time series. The effect of spot sampling by the 15-minute TR's is evident as they diverge significantly from the 15-minute average VACM spectra at frequencies above .5 cph. This is due to sampling and not inherent in the TR response time or accuracy since the 1-minute TR's do not exhibit this increase until frequencies greater than 10 cph.

Diurnal variability dominates the temperature spectra in the upper 10 m, but diurnal and semi-diurnal peaks are of comparable size at 80 m and below.

6. VELOCITY DATA PRESENTATION

Hourly wind and current values are plotted in Figure 5. Statistics of wind and current velocity are listed in Table 3 and plotted in Figure 6. Mean conditions are typical of northern hemisphere spring with a strong Equatorial Undercurrent centered at 80 m and an eastward surface flow replacing the westward South Equatorial Current (McPhaden and Taft, 1988). Mean surface wind conditions are also typical of the Southeast Trade Winds.

Spectra of the 15-minute data are plotted in Figure 7. Peaks at diurnal and semi-diurnal frequencies are present in the currents at most levels. Meridional winds and currents between 10 and 120 m (with the exception of 45 m) appear to be more energetic than zonal winds and currents at periods between 1 and 10 days.

7. ACKNOWLEDGMENTS

We would like to thank Stan Hayes (PMEL) for the loan of 10 TR's for this experiment. We also acknowledge Andy Shepherd, Doug Fenton, Carol Coho and Rick Cole for instrument preparation, calibration and mooring deployment. Funds for data collection and processing were provided by EPOCS.

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Table 1. Ocean temperature data return from EPOCS mooring EC65 and air temperature from mooring EW62 for the first 30.1 days of deployment. TR-T indicates Sea Data Temperature Recorders which recorded data on tape and TR-M TRs with solid-state memory.

Depth (m)	Instrument Type	Delta-t (min)	Data Return (days)
-3	AMP	120.	30.1
1	VAWR	15.	30.1
10	VACM	15.	30.1
25	VACM	15.	30.1
26	SEACAT	15./1.	0.0
30	TR-T	1.	15.6
34	TR-M	1.	18.5
35	TR-T	15.	30.1
36	TR-T	1.	0.0
40	TR-M	1.	30.1
45	VACM	15.	30.1
46	TR-T	1.	13.5
59	TR-T	1.	12.6
60	TR-T	15.	30.1
61	TR-T	1.	12.6
80	VACM	15.	30.1
100	TR-T	15.	30.1
101	TR-T	1.	12.1*
120	VACM	15.	30.1
121	SEACAT	15./1.	0.0
140	TR-T	15.	30.1
160	VACM	15.	30.1
200	TR-T	15.	30.1
250	VACM	15.	30.1
300	TR-M	15.	30.1

* 40% of data is bad

Table 2. Statistics of air temperature at mooring EW62 and water temperature at mooring EC65. Units are degrees C. Air temperature statistics are computed from 2-hour average time series. Water temperature statistics in upper portion of table are computed from 15-minute average or 15-minute spot sample time series. Water temperature statistics in lower portion of table are computed from 1-minute spot sample time series. Time series at 101 m has gaps for 40% of record. All time series begin on May 12, 1987, at 1000Z.

Temperature at 0°, 140°W

Depth	Day	N	MEAN	VAR	SKEW	MIN	MAX
-3 m	30.1	361	28.29	0.323	-1.581	25.38	29.07
1 m	30.1	2891	28.97	0.055	-0.079	28.43	29.92
10 m	30.1	2891	28.91	0.045	-0.334	28.47	29.29
25 m	30.1	2891	28.84	0.049	-0.296	28.37	29.21
35 m	30.1	2891	28.82	0.073	-0.283	27.93	29.26
45 m	30.1	2891	28.56	0.142	-0.571	27.40	29.14
60 m	30.1	2891	27.97	0.166	0.186	26.58	29.05
80 m	30.1	2891	26.13	1.118	-0.888	22.17	28.00
100 m	30.1	2891	23.90	2.788	-0.174	19.97	27.16
120 m	30.1	2891	18.27	1.027	0.461	16.05	21.50
140 m	30.1	2891	16.48	0.597	0.419	14.73	19.98
160 m	30.1	2891	14.98	0.427	-0.019	13.35	16.98
200 m	30.1	2891	13.05	0.095	0.813	12.52	14.81
250 m	30.1	2891	12.44	0.020	-0.245	11.99	12.77
300 m	30.1	2891	11.76	0.135	-0.966	10.75	12.39
30 m	15.6	22447	28.67	0.028	-0.124	28.18	29.00
34 m	18.5	26671	28.67	0.035	-0.535	27.91	29.02
40 m	30.1	43375	28.74	0.104	-0.484	27.71	29.27
46 m	13.5	19471	28.29	0.110	-0.562	27.37	28.87
59 m	13.0	18703	27.80	0.106	0.077	27.07	28.62
61 m	12.6	18223	27.72	0.102	0.104	26.90	28.57
101 m	12.1	10384	22.82	2.772	0.519	19.60	27.80

Table 3. Statistics of wind at mooring EW62 and currents at mooring EC65. Units are m/s for wind and cm/s for current. Wind statistics are computed from 2-hour vector-average time series. Current statistics are computed from 15-minute vector-average time series. All time series begin on May 12, 1987, at 1000Z.

Zonal Velocity at 0°, 140°W

Depth	Day	N	MEAN	VAR	SKEW	MIN	MAX
-4 m	30.1	361	-3.49	3.39	0.42	-7.42	2.55
10 m	30.1	2891	57.37	143.03	-0.24	23.56	84.07
25 m	30.1	2891	59.33	102.38	0.81	41.58	91.77
45 m	30.1	2891	95.33	216.22	-0.62	50.93	126.18
80 m	30.1	2891	114.83	211.26	0.13	74.73	153.18
120 m	30.1	2891	103.53	57.26	-0.02	76.57	124.90
160 m	30.1	2891	64.65	92.32	0.21	37.44	96.76
250 m	30.1	2891	13.60	111.55	-0.38	-16.03	40.42

Meridonal Velocity at 0°, 140°W

Depth	Day	N	MEAN	VAR	SKEW	MIN	MAX
-4 m	30.1	361	1.20	3.74	0.22	-4.09	5.94
10 m	30.1	2891	8.71	203.61	-0.25	-36.53	53.68
25 m	30.1	2891	7.97	125.20	-0.22	-27.67	40.34
45 m	30.1	2891	10.66	175.33	-0.09	-31.20	48.67
80 m	30.1	2891	10.87	288.57	-0.13	-41.17	58.57
120 m	30.1	2891	7.04	162.79	0.34	-30.37	53.54
160 m	30.1	2891	5.48	105.36	-0.08	-25.54	35.53
250 m	30.1	2891	1.57	156.34	-0.43	-37.72	27.48

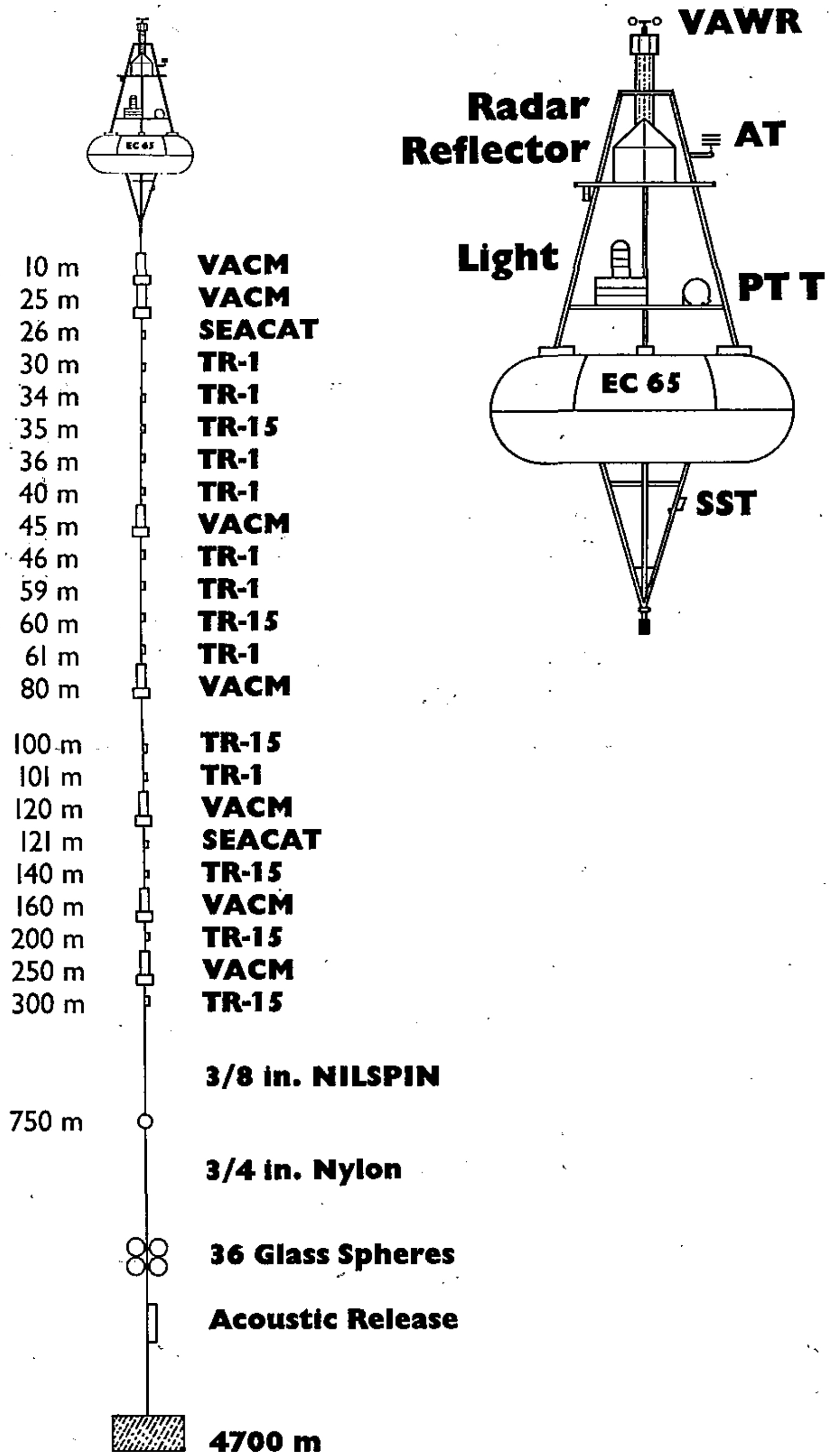


Figure 1. Schematic drawing of mooring EC65 (not to scale). Instrumentation on surface buoy includes Vector Averaging Current Meter (VAWR) with air temperature (AT) and sea surface temperature (SST) sensors and Argos platform transmitter terminal (PTT).

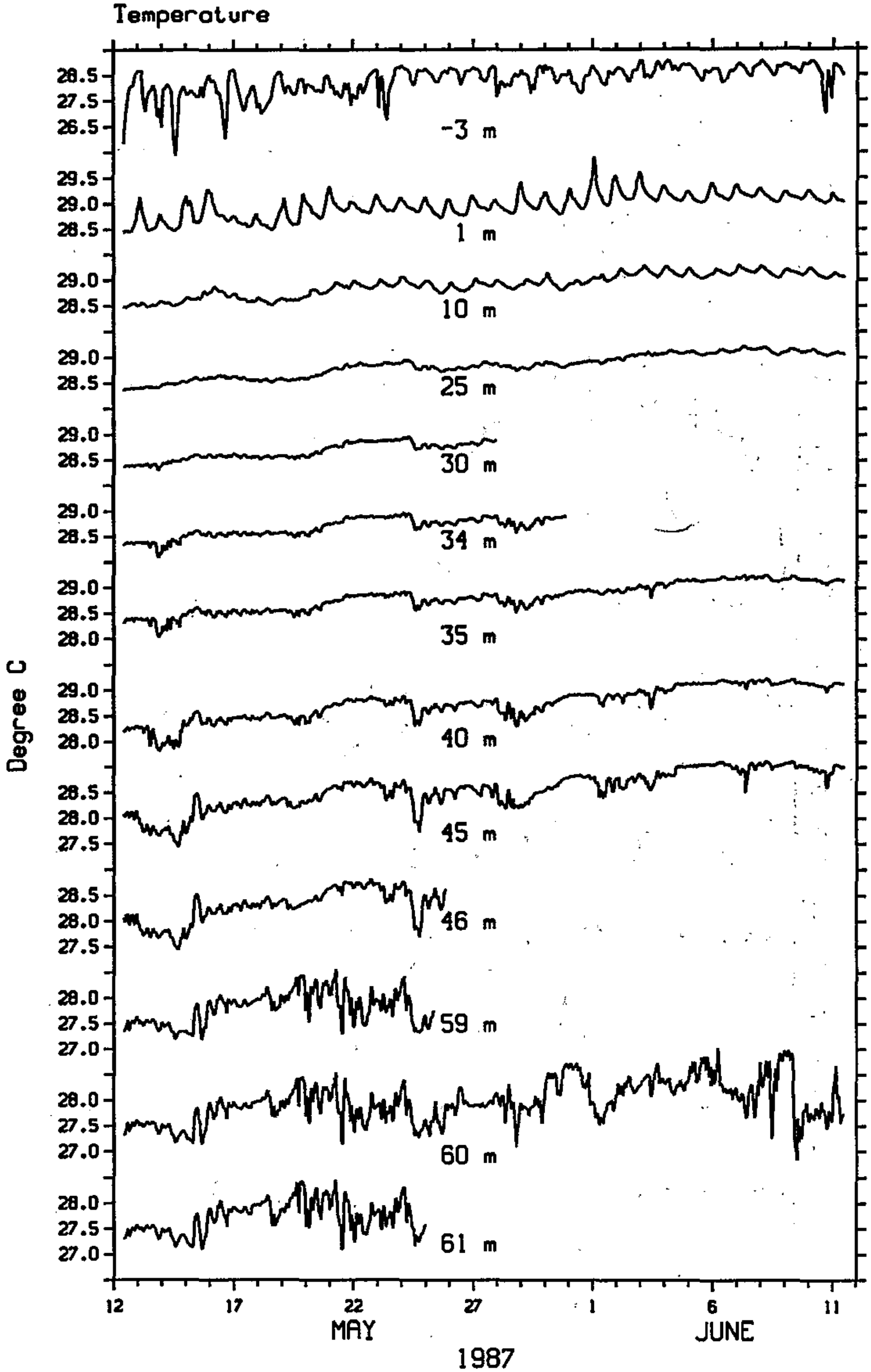


Figure 2a. Hourly average values of temperature, -3 m to 61 m.

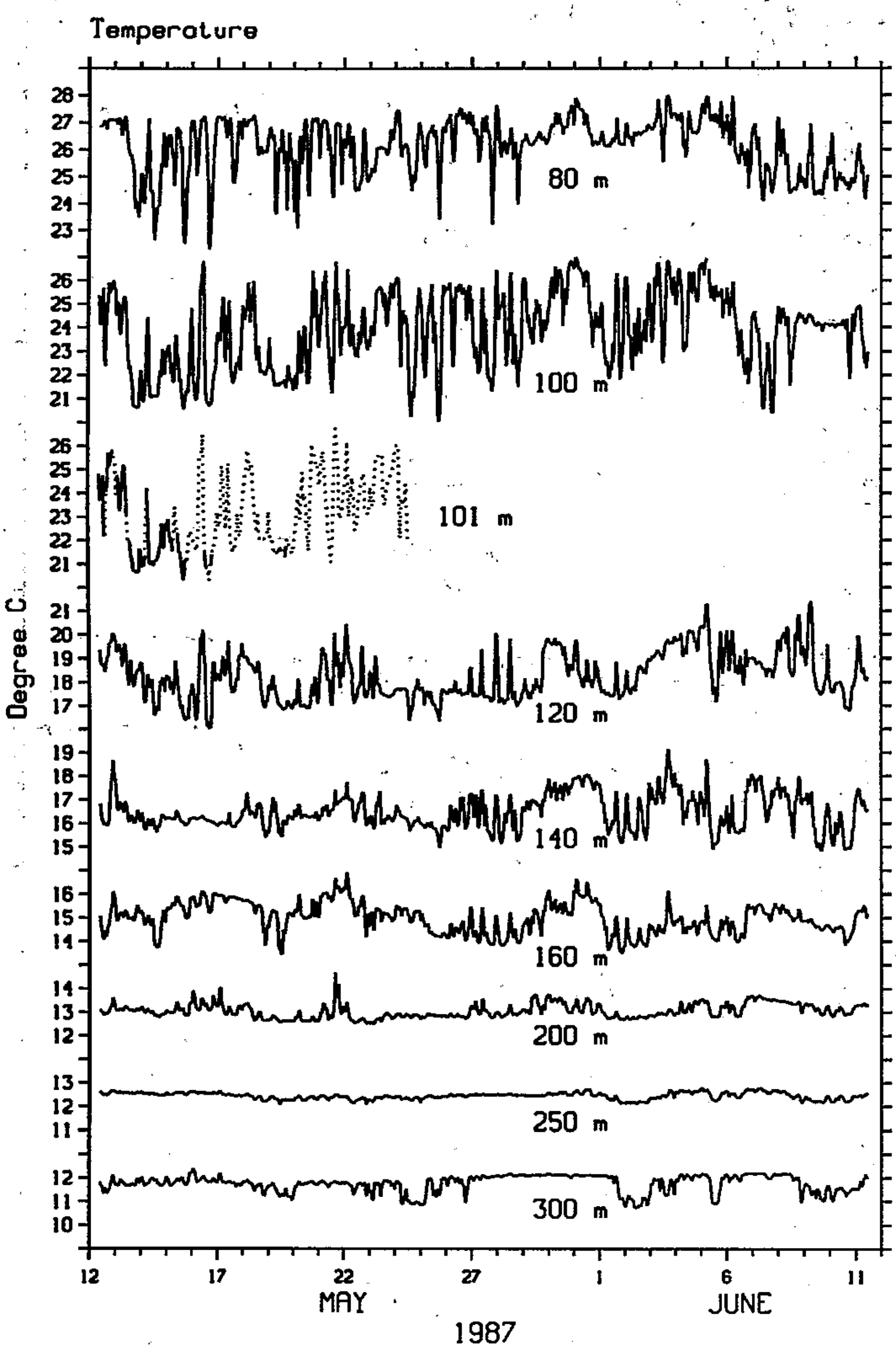


Figure 2b. Hourly average values of temperature, 80 to 300 m. Dashed line indicates gappy data (see text).

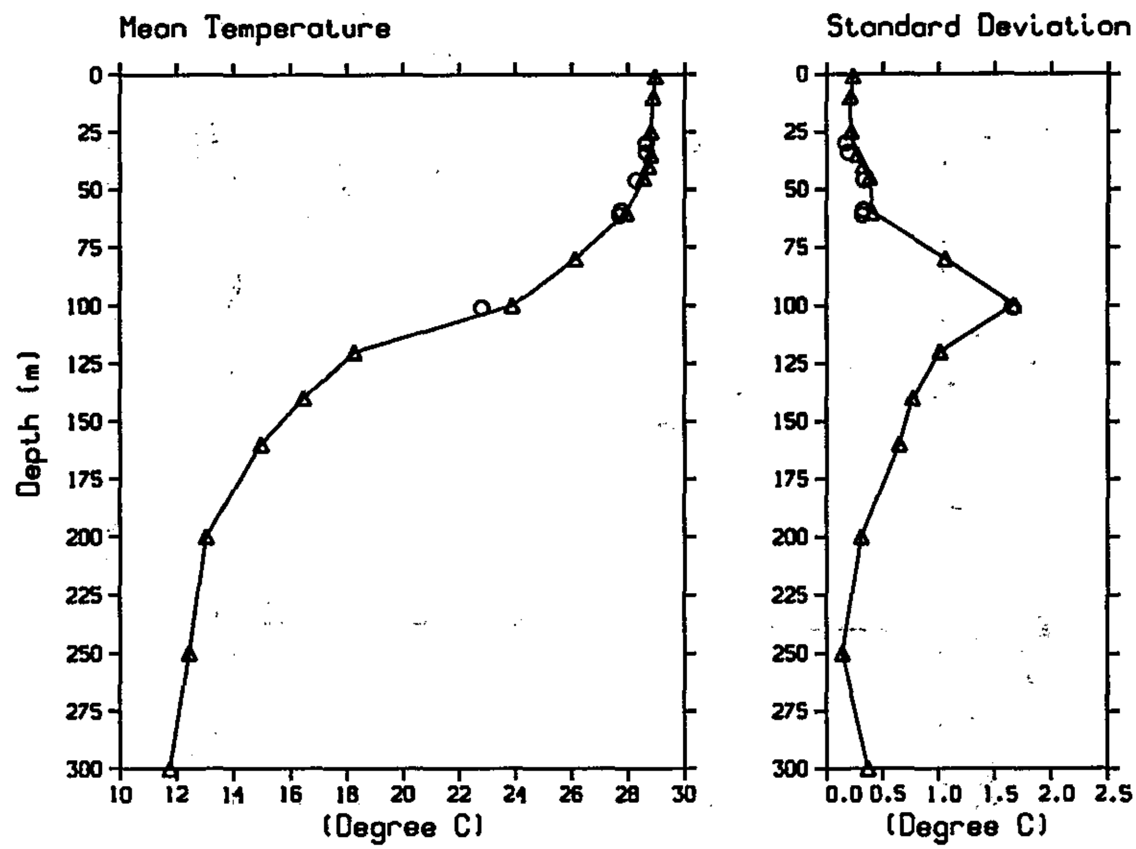


Figure 3. Temperature mean and standard deviation. Triangles are for 30.1 day records. Circles are shorter records (see Table 1).

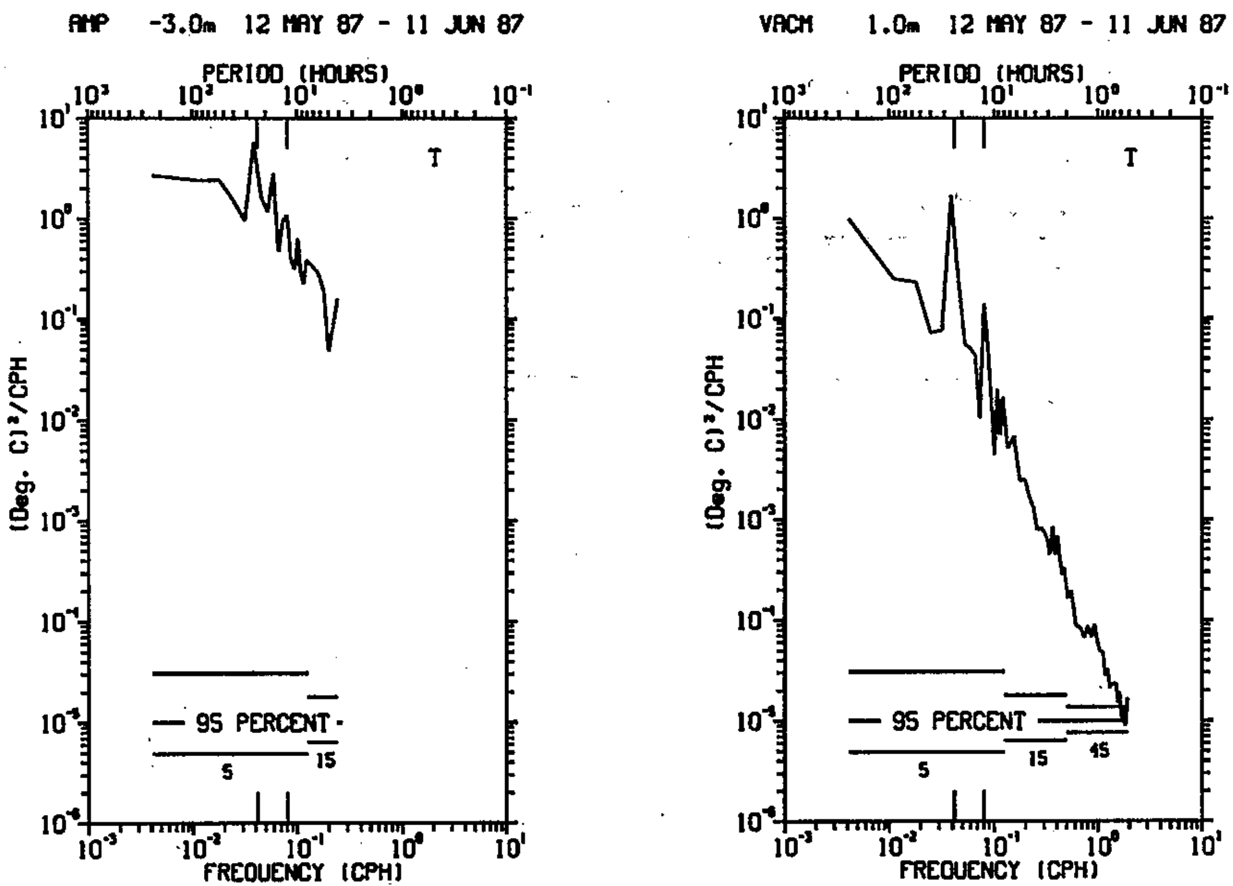


Figure 4. Spectral density of temperature.

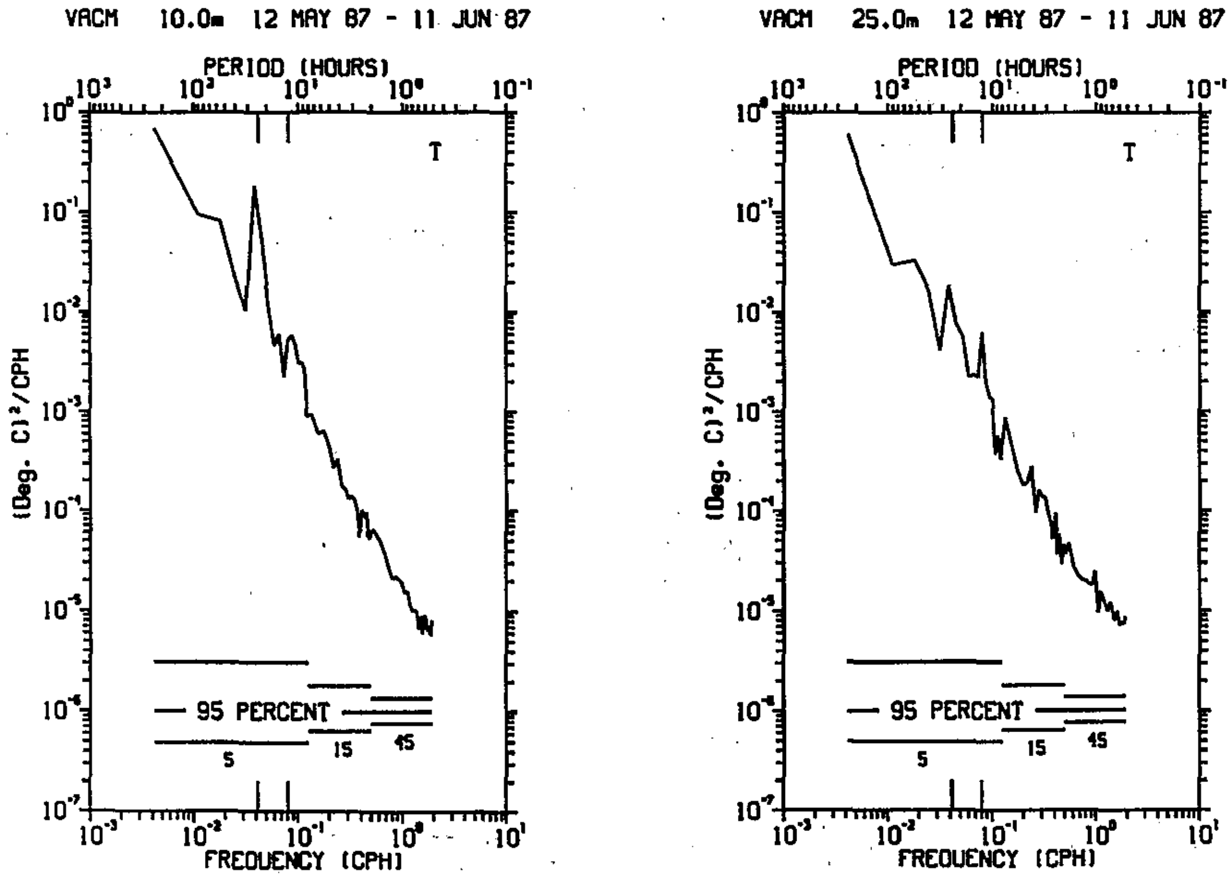
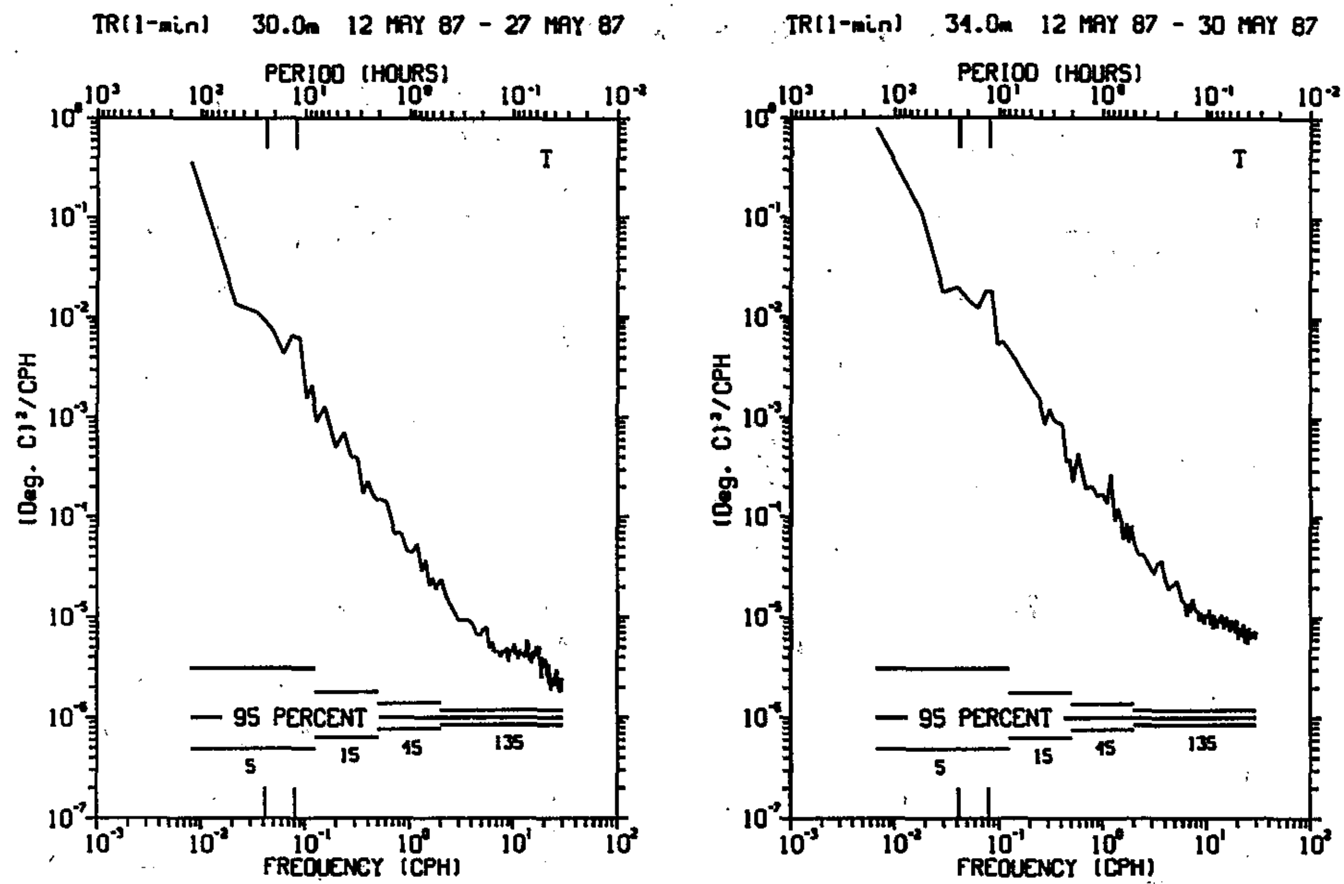


Figure 4 (continued). Spectral density of temperature.



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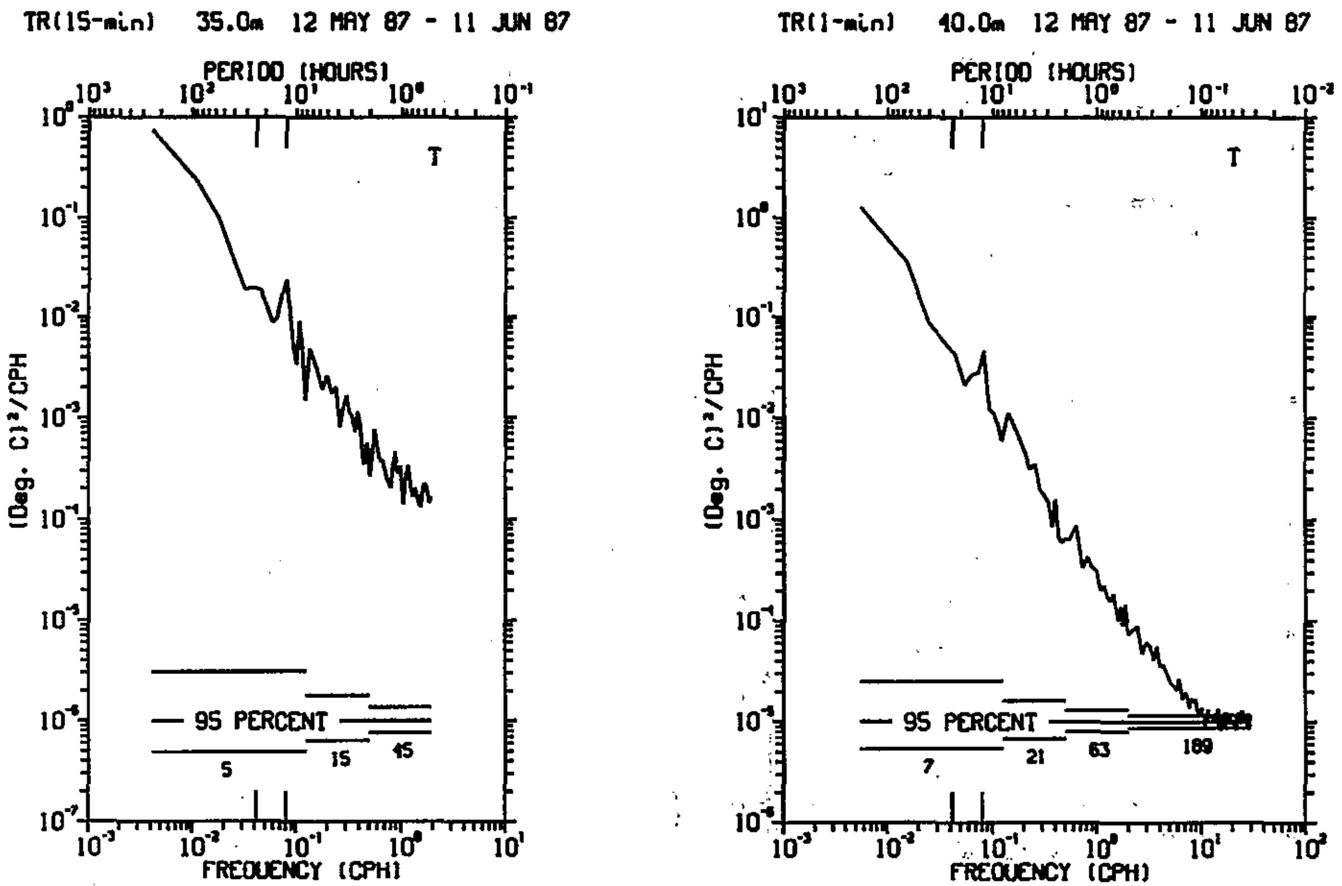

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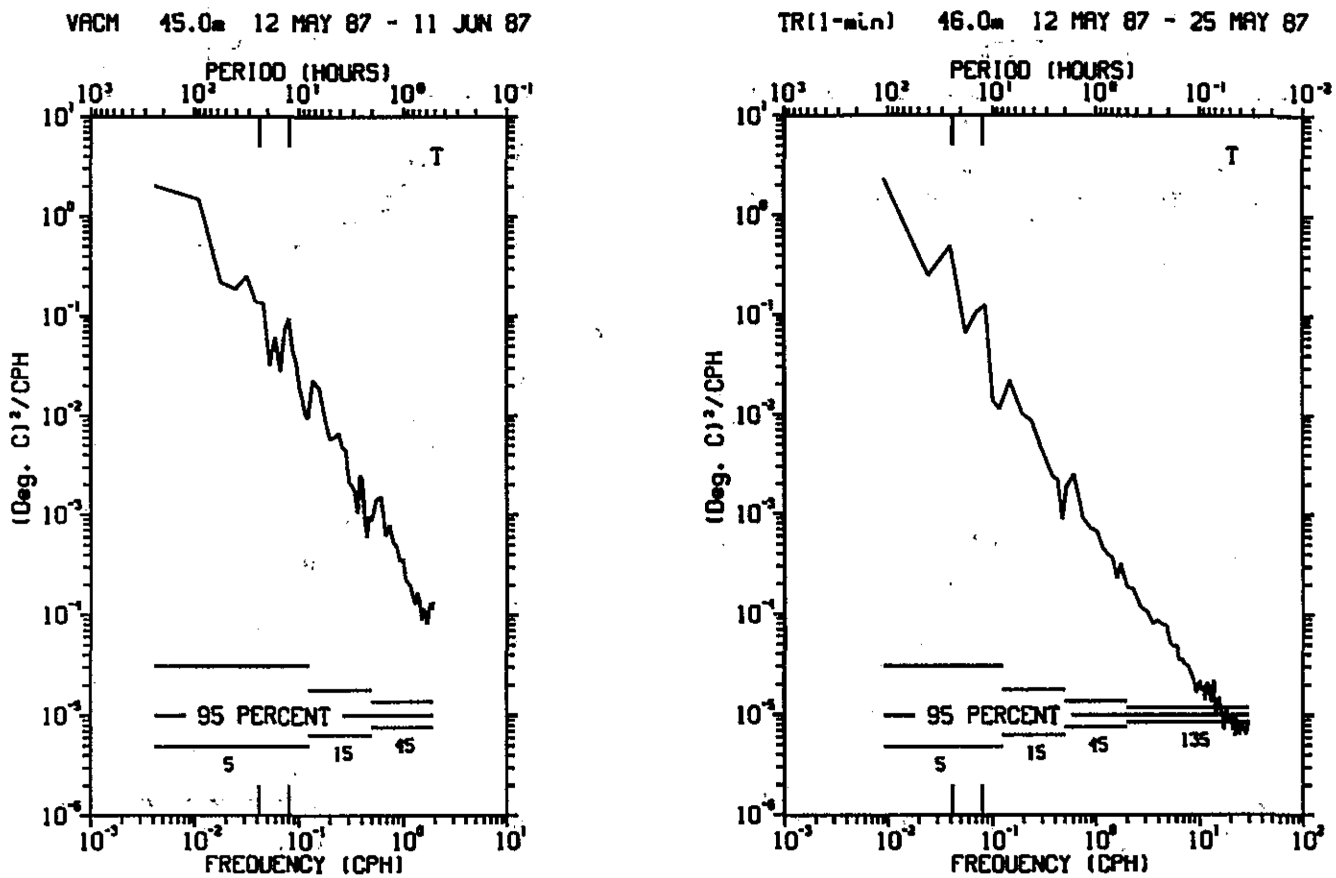

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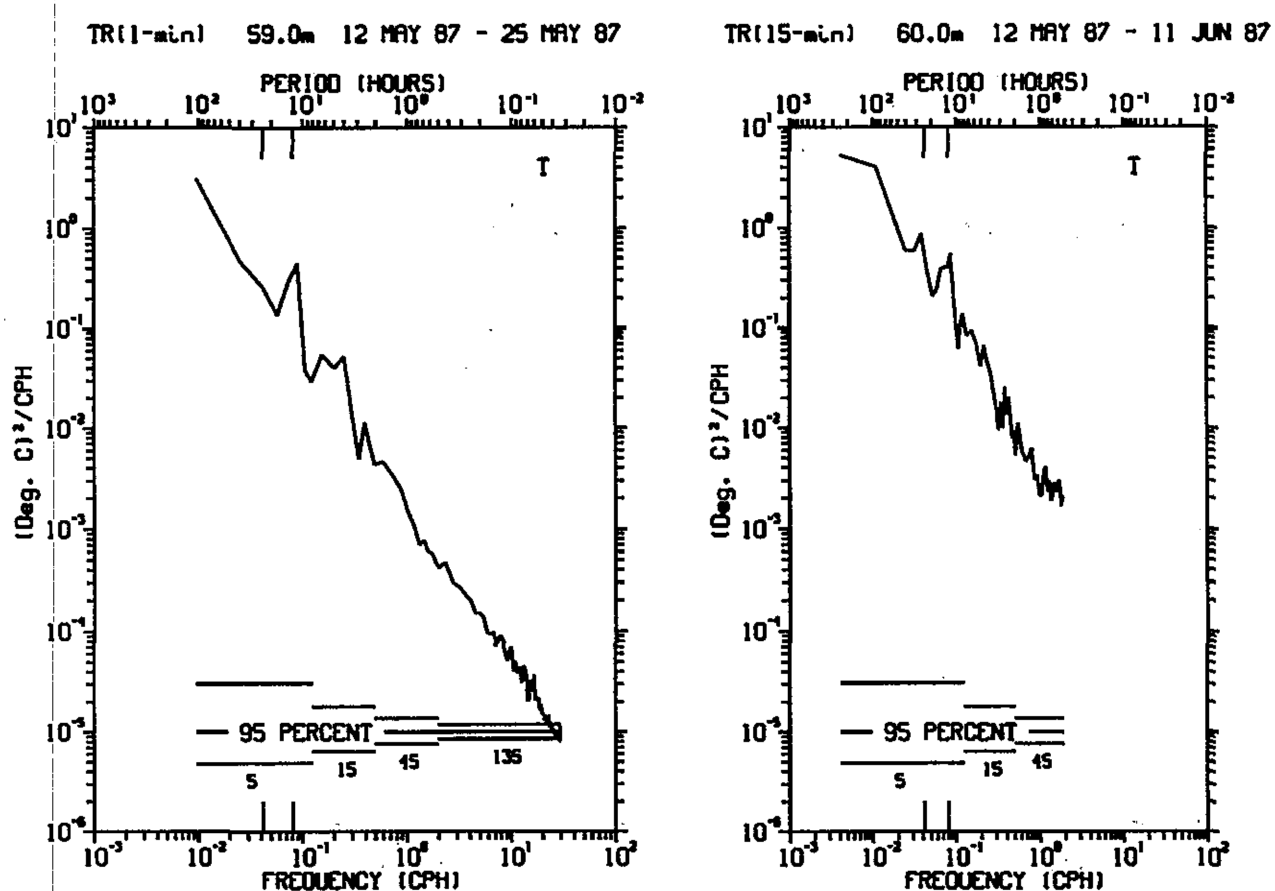

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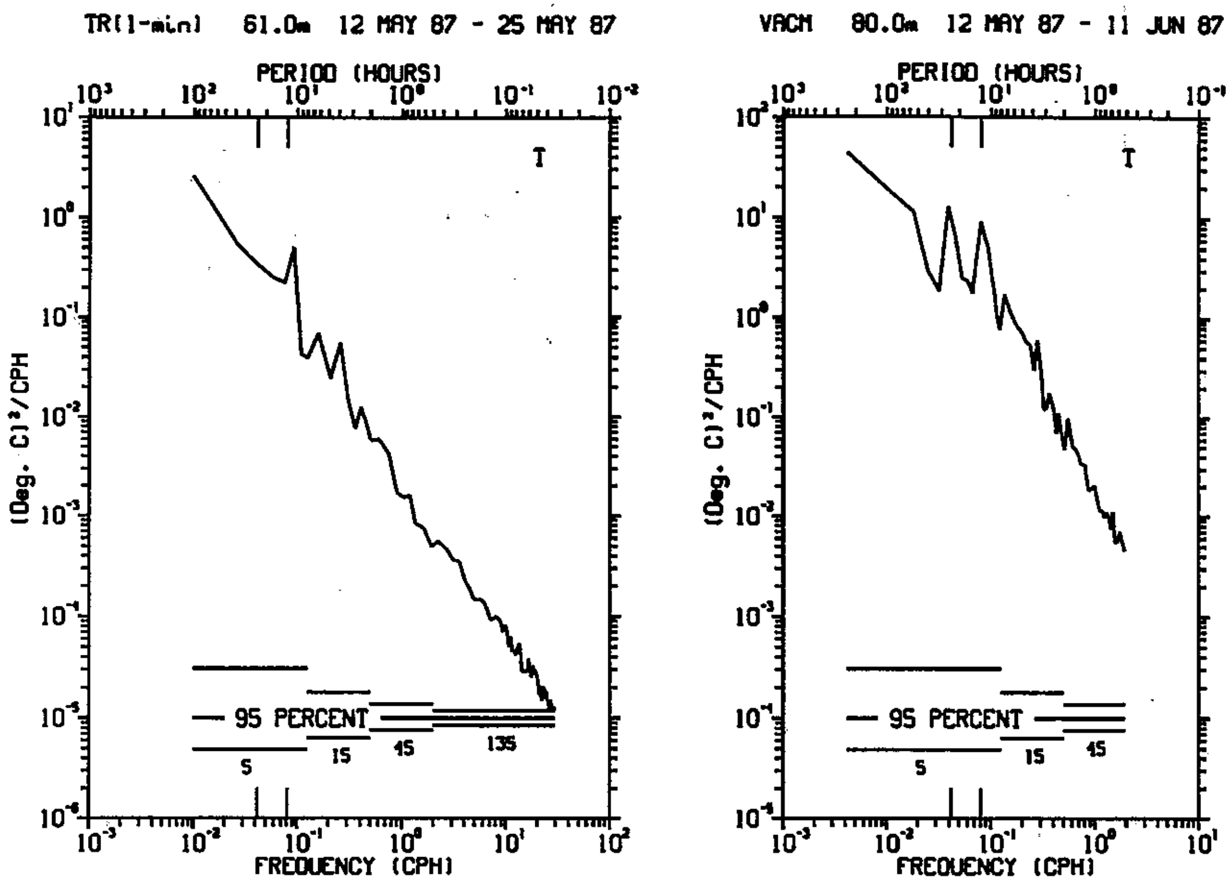

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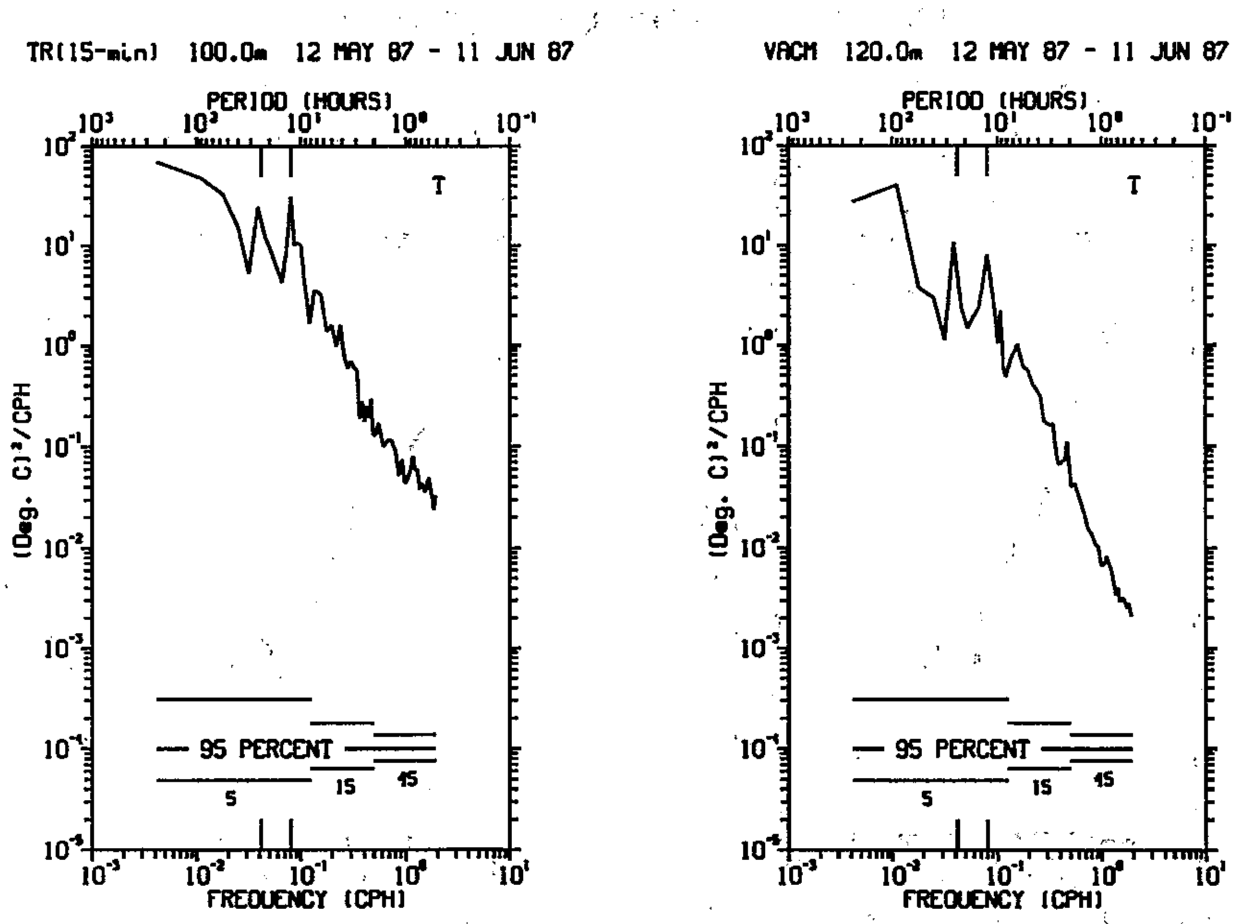

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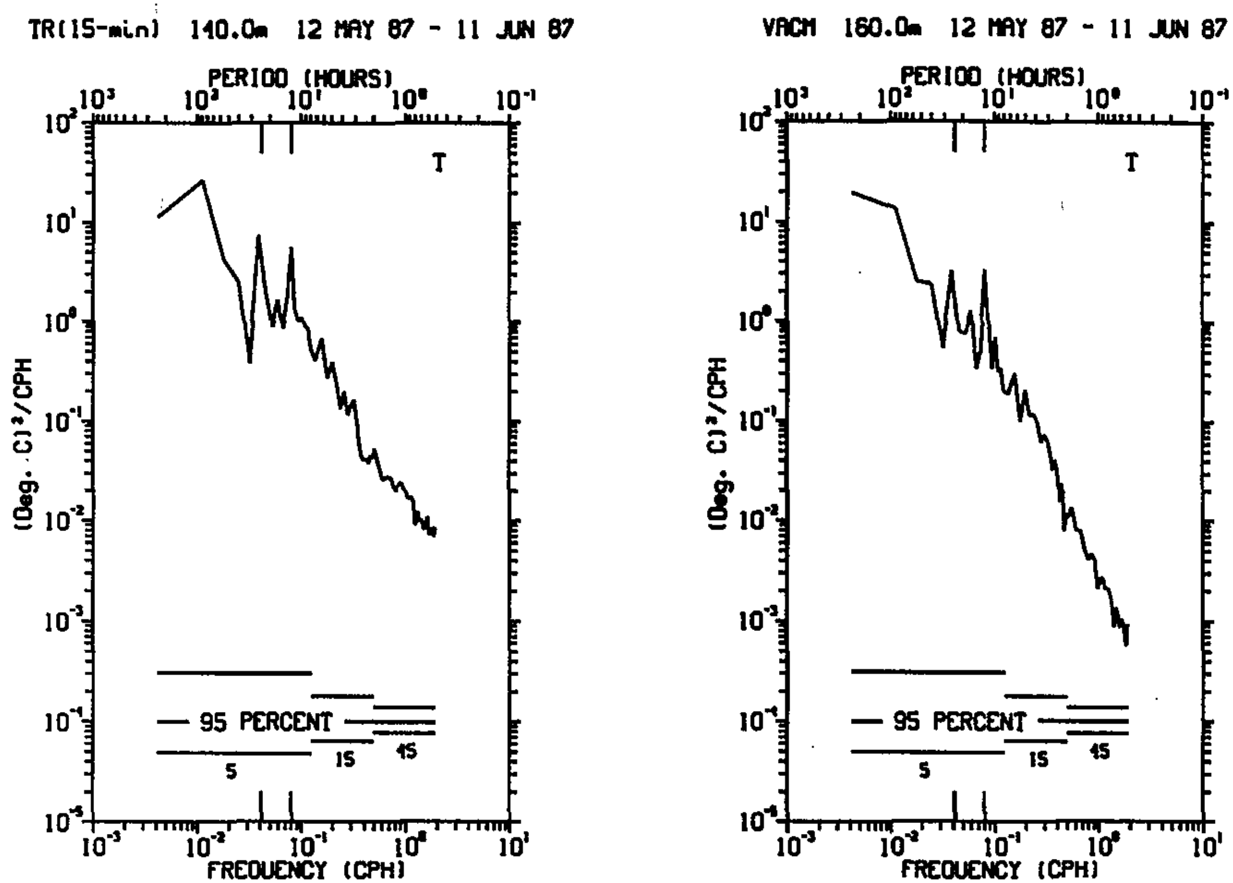

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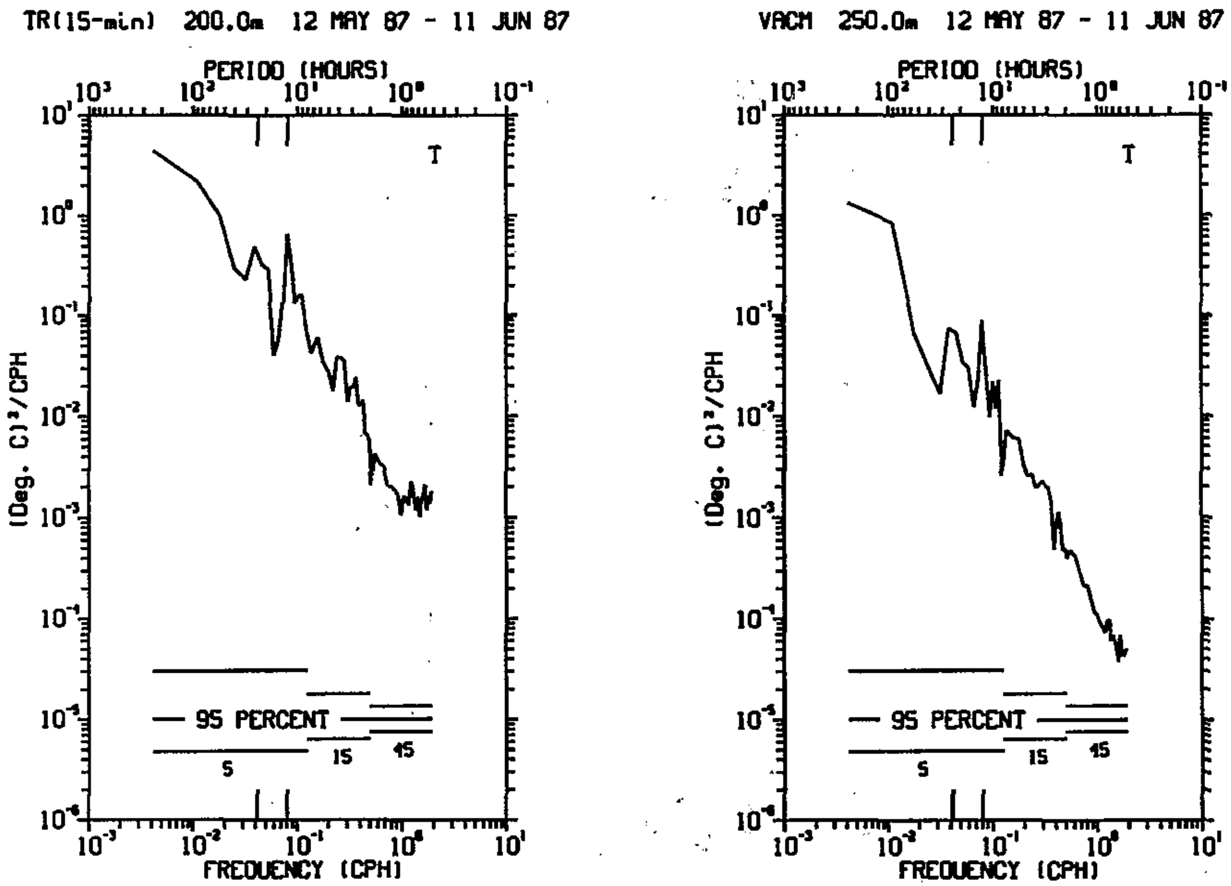

Figure 4 (continued). Spectral density of temperature.

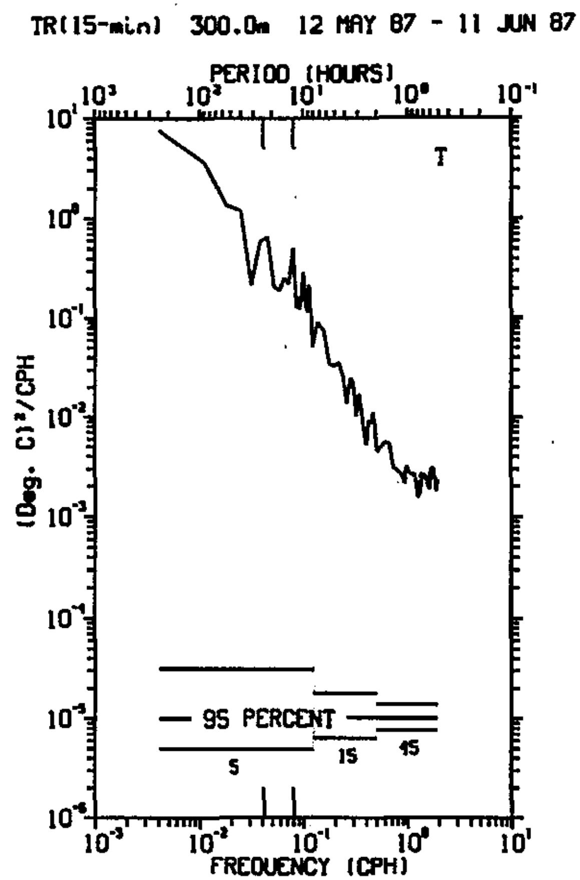

Figure 4 (continued). Spectral density of temperature.

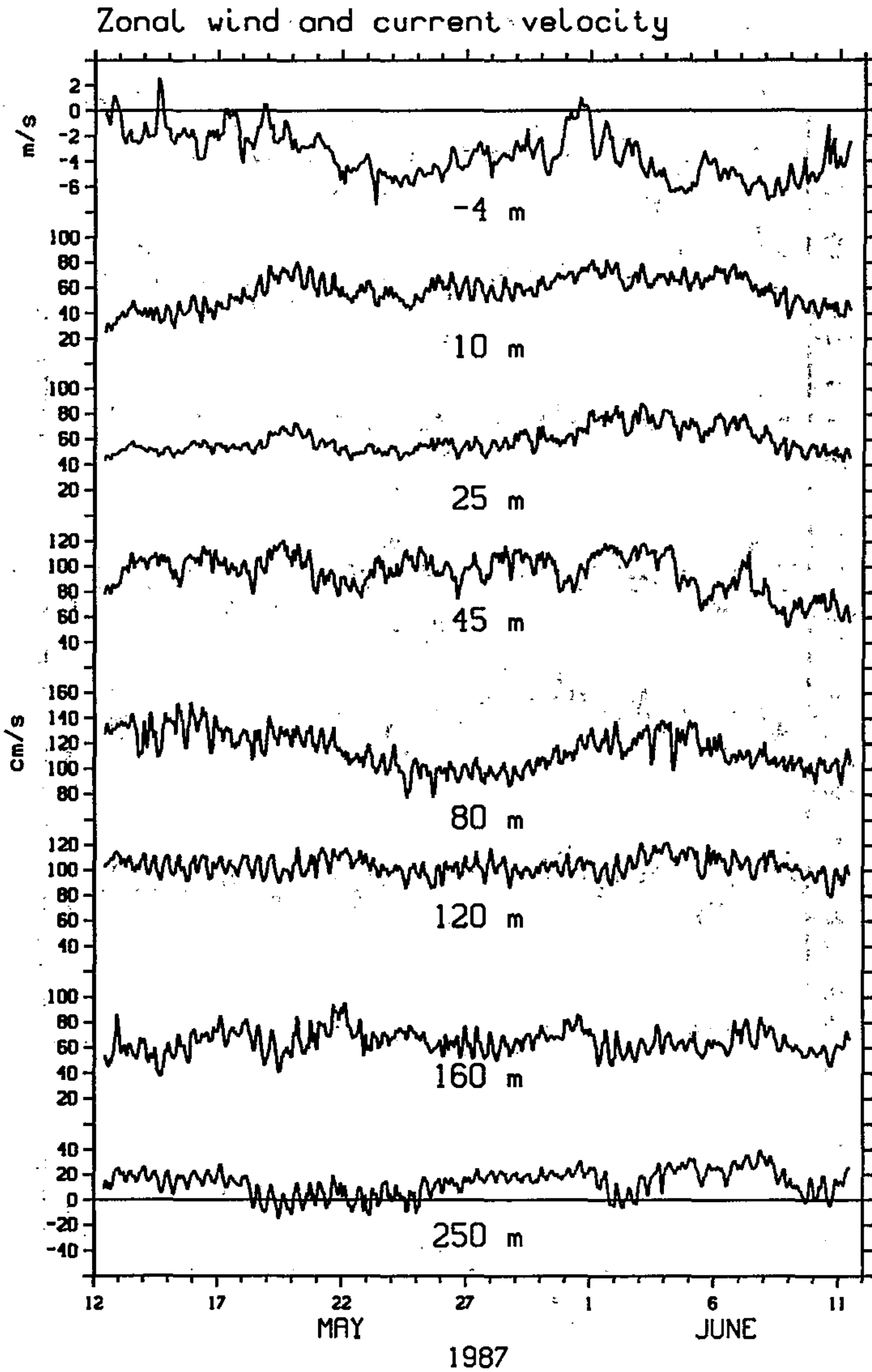

Figure 5a. Hourly average values of wind and current velocity; zonal component.

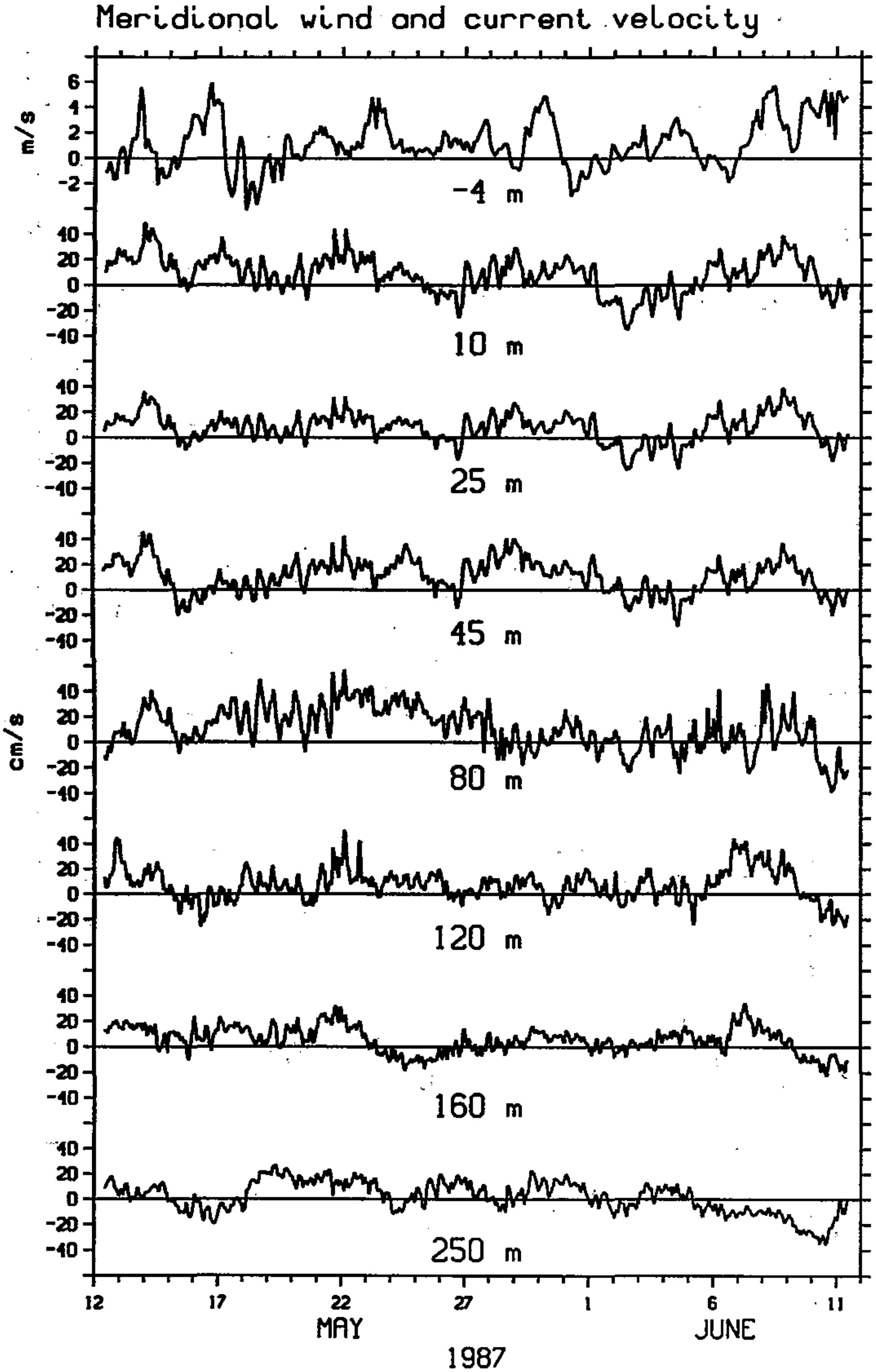

Figure 5b. Hourly average values of wind and current velocity; meridional component.

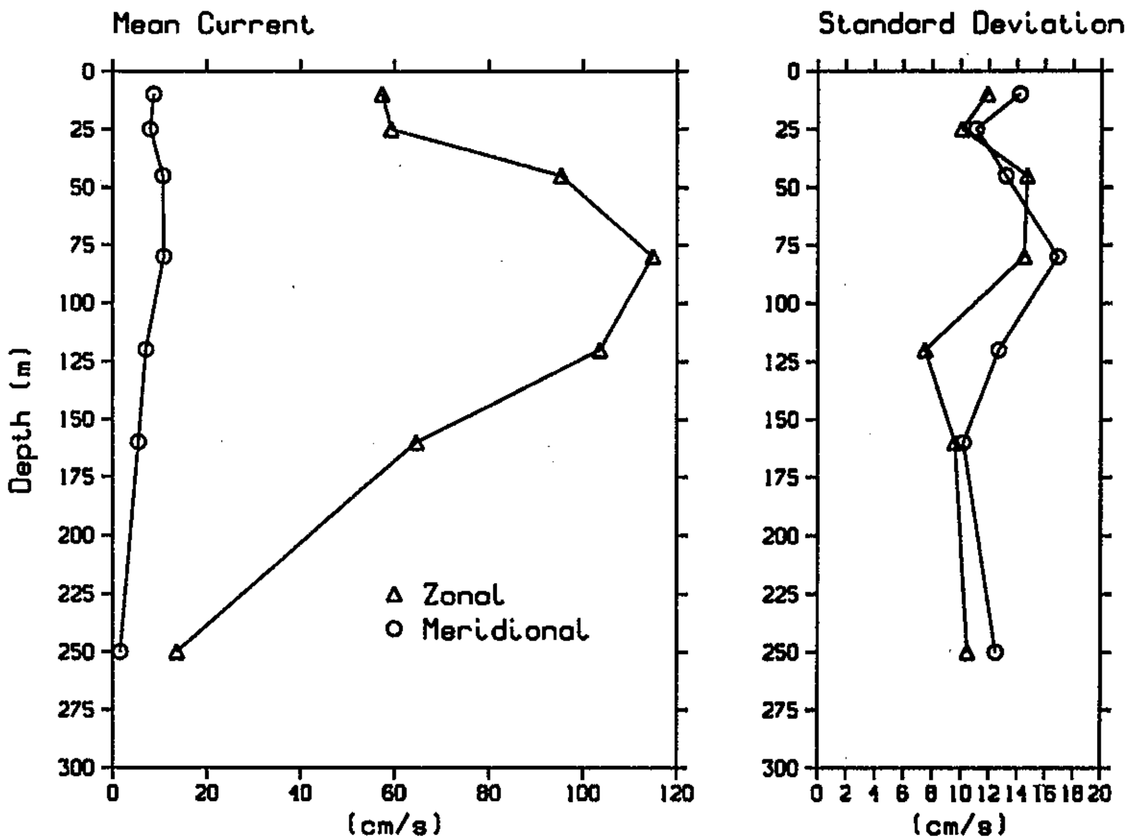

Figure 6. Mean and standard deviation of zonal (triangle) and meridional (circle) current velocity.

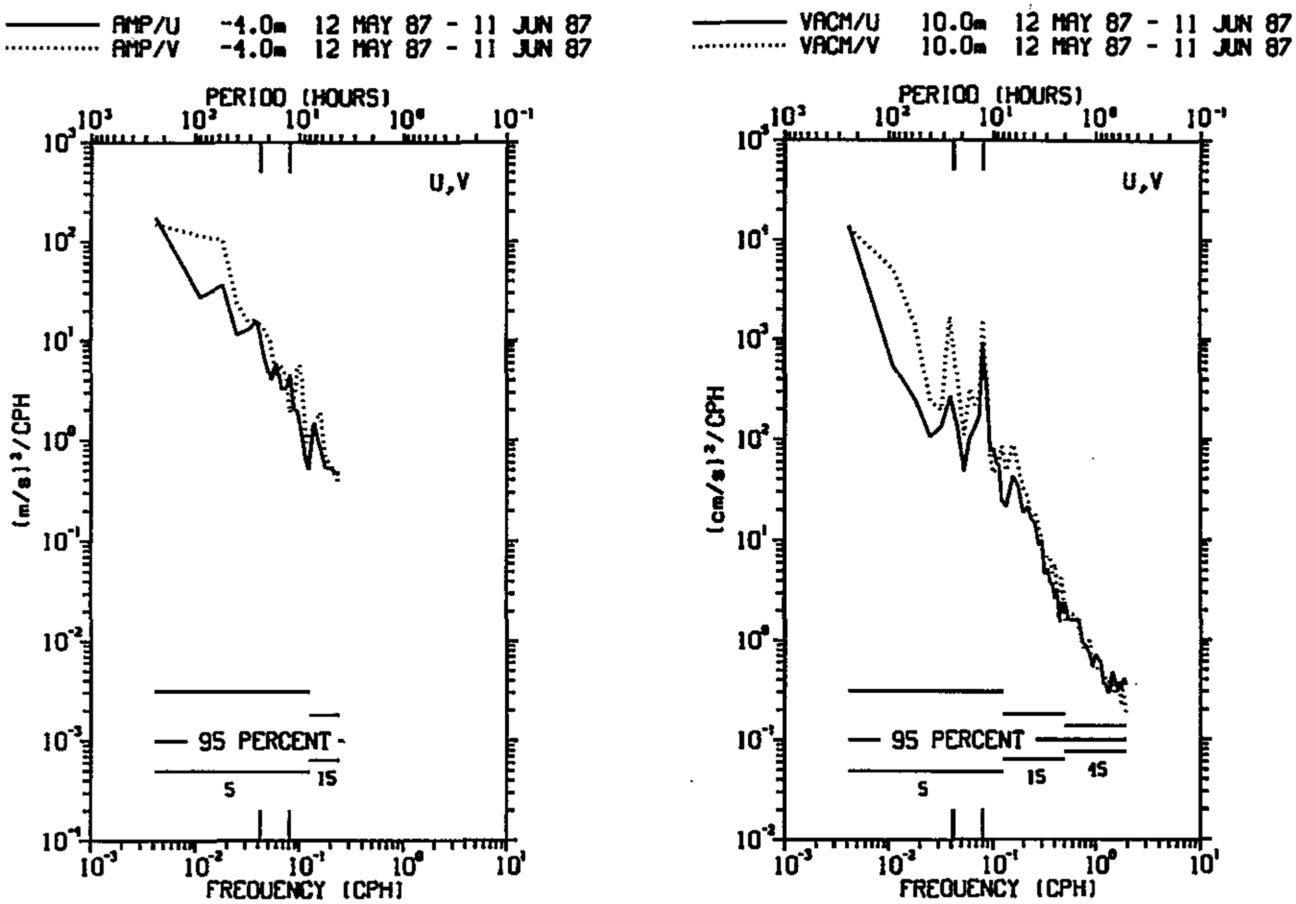

Figure 7. Spectral density of zonal (solid) and meridional (dashed) wind and current.

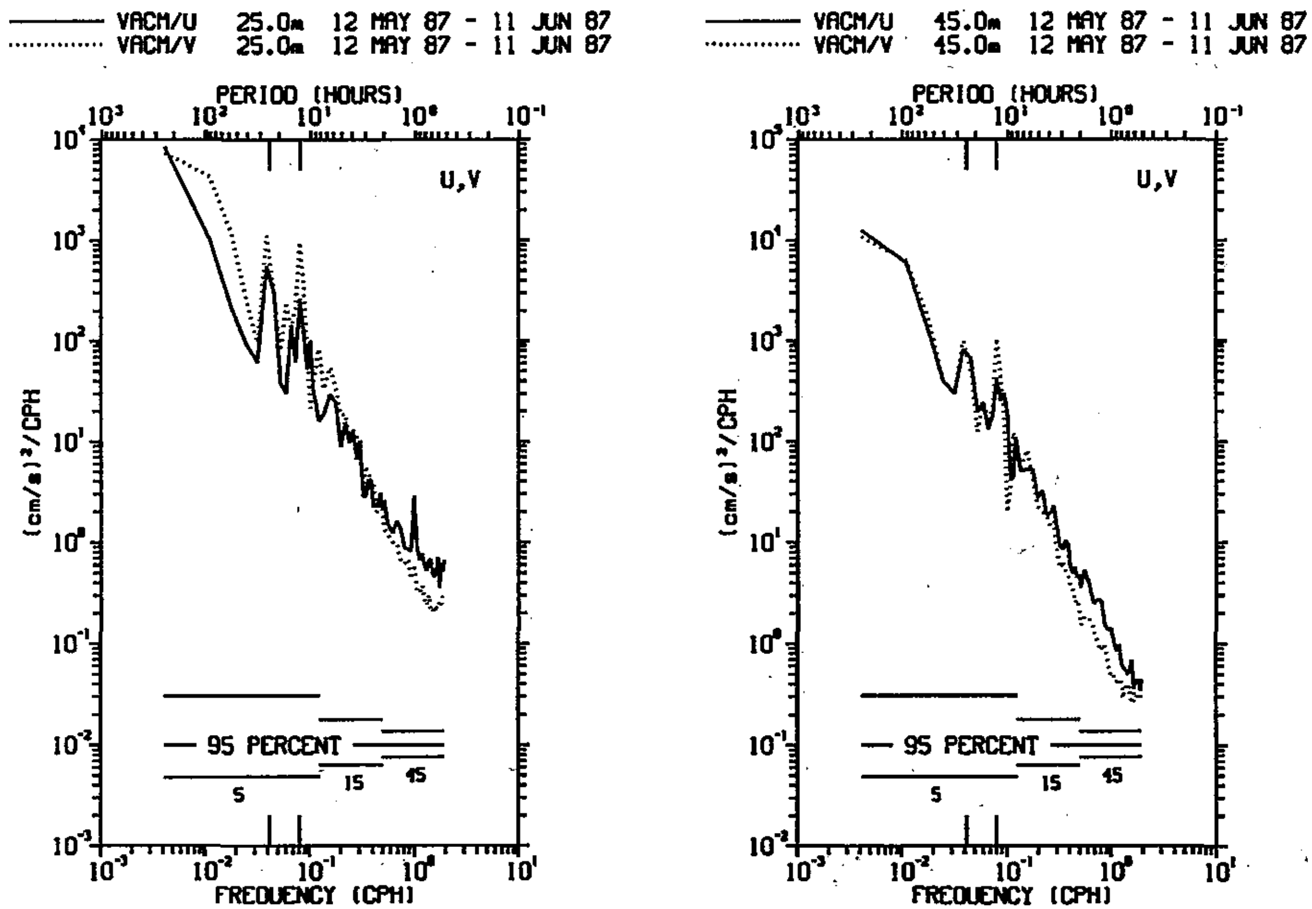

Figure 7 (continued). Spectral density of zonal (solid) and meridional (dashed) wind and current.

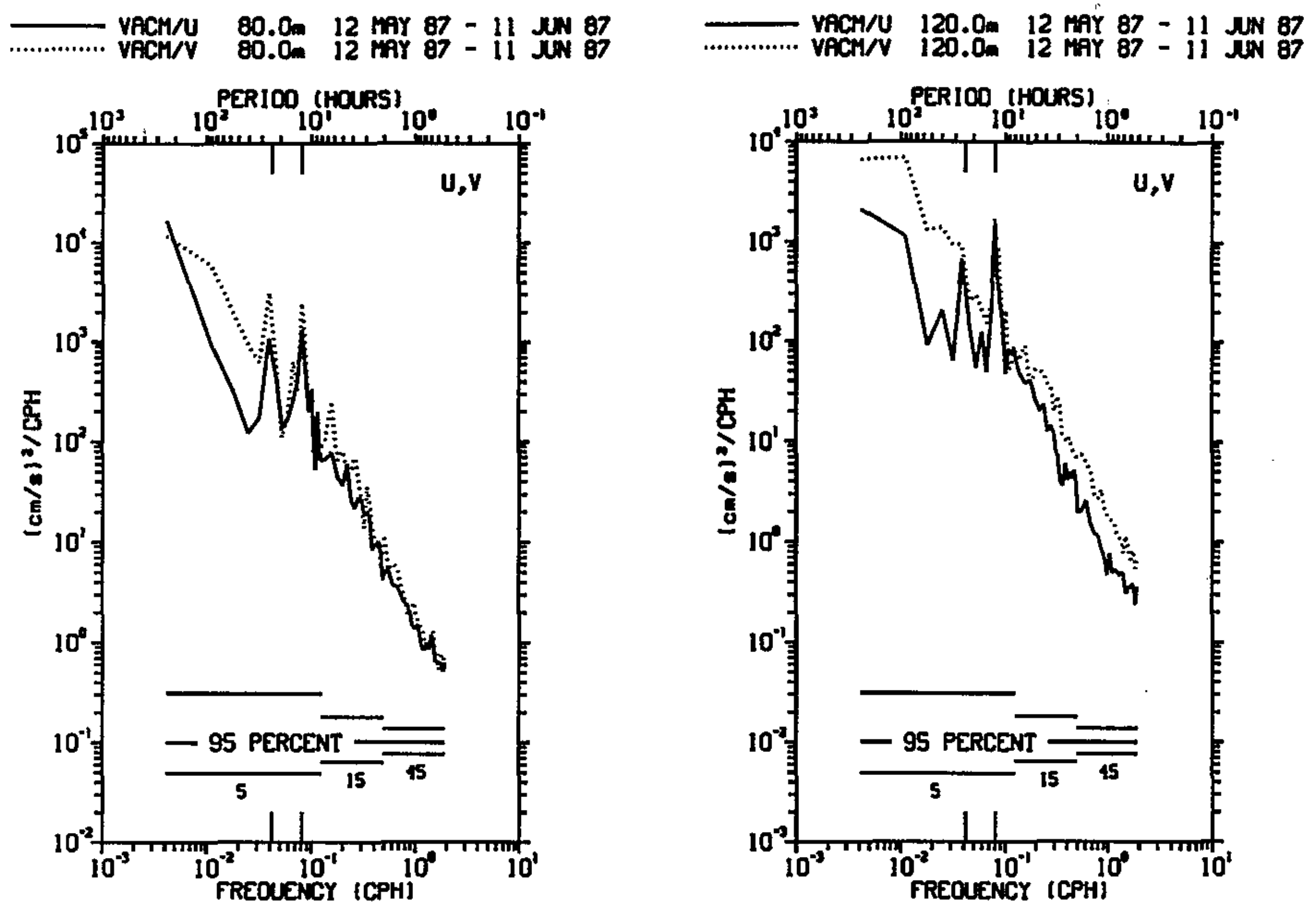

Figure 7 (continued). Spectral density of zonal (solid) and meridional (dashed) wind and current.

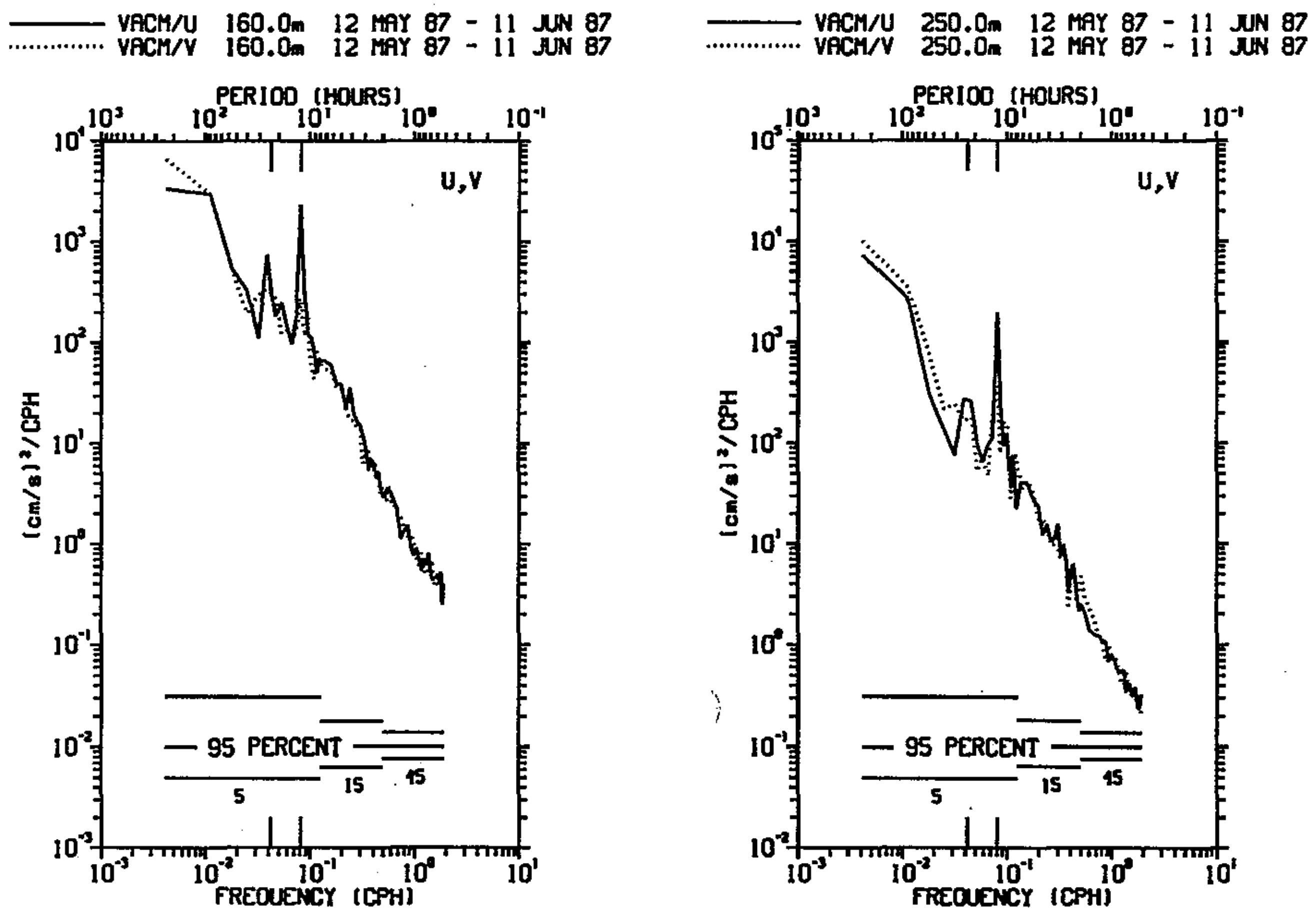

Figure 7 (continued). Spectral density of zonal (solid) and meridional (dashed) wind and current.